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## 投稿規定

1　資　格

原則として，気象庁職員に限る。ただし，気象庁職員との連名の場合は，この限りでない。

2　論文及び報文（以下「論文等」という。）の内容

未発表の原稿で，海洋（物理・化学・生物・地質など）及び海上気象（波浪・海水・海気相互関係など）に関する論文並びに気象庁における海洋・海上気象業務の活動，そのために開発された測器及び方法に関する報文など。

3　書き方

(1) 用語は，欧文（原則として英文）とする。

(2) 論文等には，英文（300語以内）及び和文（800字以内）の要約を付ける。要約は，方法・測器・実験・観測の結果・仮定・理論などの中味が読みとれるように留意し，なるべく指定の長さで簡潔に書く。

(3) 論文等の始めには，題名・著者名及所属機関名を明記する。和文の要約にも同様のことを明記する。

(4) 原稿は，厚手の用紙にダブルスペースでタイプする。

(5) 図は，白紙又は青方眼紙に墨入れし，図及び図中の文字の大きさは，印刷の際の縮小率を考えて作成する。特に重要な図は，投稿者が大きさを指定する（印刷の都合上，希望どおりにならないこともある。）

(6) 図（写真を含む。）及び表には，必ず説明を付ける。図の説明文は，別紙にタイプする。折り込みの図及び表は，なるべく避ける。図及び表のそう入箇所を本文の欄外に記入する。

(7) 数式は，2行取りに書き，数式の文字及び記号をはっきりと説明する。

(8) 論文等の中に文献を引用する場合は，「Allen (1927)」又は「(Allen, 1927)」のように書く。

(9) 引用文献は，最後にまとめて付け，著者名のアルファベット順に並べる。書き方は次のようにする。

Allen, W.E. (1927): Surface catches of marine diatoms and dinoflagellates made by U.S.A. Pioneer in Alaskan waters in 1923. *Bull. Scripps Inst. Occanogr., Tech. Ser.* 1(4), 39–48.

Budyko, M. I. (1956): *The heat balance of the earth's surface.* Hydrometeorogical Publishing House, Leningrad, pp. 254.

Veronins, G. and H. Stommel (1956): The action of a variable wind stress on a stratified ocean. *J. Mar. Res.*, 15(1), 43–75.

4　提出方法

投稿票を付け，本稿のほかにコピー（図及び表を含む。）2部を添える。

5　締切り

毎年気象庁公報により公示する。

6　送付先

気象庁海洋気象部海洋課

（原則として，書留便で送付する。）

7　その他

論文1等編につき別刷り50部を著者に無料で送付する。

Oceanographical Magazine

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# The distribution of *Calanoides philippinensis* KITOU et TANAKA, Copepoda, in the East China Sea

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(Received November 24, 1977; revised January 5, 1978; accepted January 11, 1978)

***Abstract***: About 400 specimens of *Calanoides philippinensis* were found in the plankton samples collected on board of the R/V Shumpū Maru of the Kōbe Marine Observatory and the R/V Chōfū maru of the Nagasaki Marine Observatory during their cruises in the East China Sea from 1955 to 1967.

More than 300 individuals of *C. philippinensis* were found in the samples collected from the deeper layers at nine stations out of the twelve located in the Kuroshio regions of the East China Sea and of the Pacific Ocean. This species is considered to be very common in the deeper layers of the East China Sea.

Some individuals of this species occurred at the outer edge of the continental shelf, but no individual was found in other areas of the East China Sea.

Taking account of the oceanographic conditions, especially of temperature-salinity relationships, *C. philippinensis* found at the outer edge of the continental shelf seem to have been carried upward by the ascending of the deep water of the Kuroshio. Then, the distribution of *C. philippinensis* is considered to prove that the deep water of the Kuroshio invades the bottom layer of the outer edge of the continental shelf.

## 1. Introduction

*Calanoides philippinensis* KITOU et TANAKA have been described by KITOU and TANAKA (1969) in the samples collected from the deep water of the South China Sea as a species closely related to *C. carinatus* (KRÖYER).

About 400 specimens of *Calanoides* were found in the plankton samples collected on board of the R/V Shumpū Maru of the Kōbe Marine Observatory and the R/V Chōfū Maru of the Nagasaki Marine Observatory during their cruises in the East China Sea from 1955 to 1967. These specimens were identified with *C. philippinensis* by the shapes of the genital organ of the female and of the 5th pair of legs of the male.

In the East China Sea, there is a wide continental shelf, which is covered by cold coastal waters from the coast of China and from the Yellow Sea. On the other hand, the warm oceanic water, Kuroshio, flows over the continental slope. Therefore, the oceanographic conditions along the outer edge of the continental shelf are much

influenced by these two types of waters.

The main purpose of the present study is to investigate the influence of the Kuroshio deep water on the bottom water of the continental shelf from the characteristic distributions of *C. philippinensis*.

## 2. Materials and methods

The observation cruises were carried out twice or more a year, by the R/V Shumpū Maru before 1962 and the R/V Chōfū Maru from 1963 to 1967, covering almost all areas of the East China Sea and parts of the Pacific Ocean (Fig. 1).

Four types of net were used for plankton sampling. O-net, a Hensen type opening net with mouth diameter of 0.36 m, was hauled vertically from 100 m depth or from the bottom if the bottom depth is less than 100 m, to the surface. C-net, a Nansen

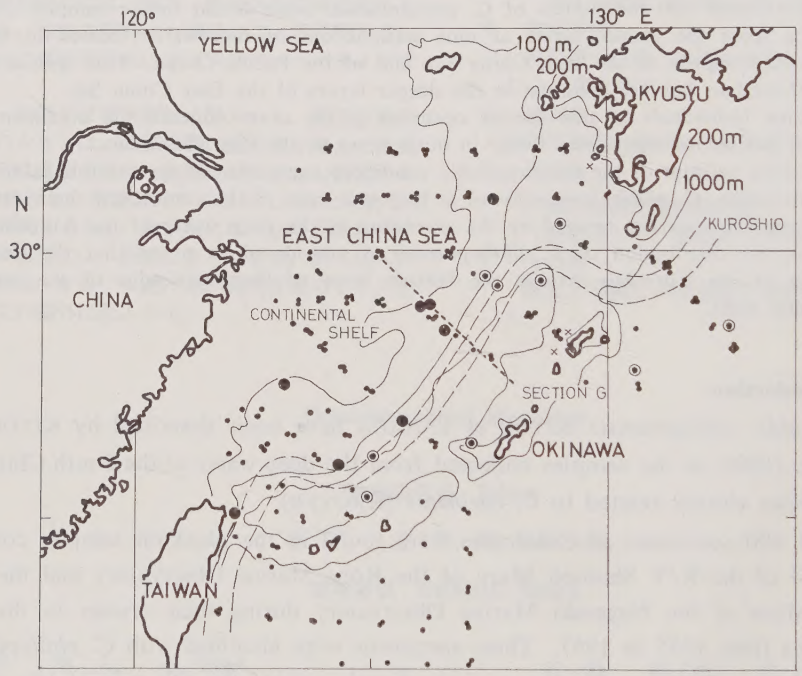


Fig. 1. Station location chart.
A mark • denotes the station where *C. philippinensis* were absent in the shallow layer sample and a mark ● denotes the station where the species was caught in the shallow layer. A mark × denotes the station where *C. philippinenses* were absent in the deep layer sample and a mark ⊙ denotes the station where the species was caught in the deep layer.

type closing net with mouth diameter of 0.51 m, was hauled vertically and plankton samples were collected from various layers below the depth of 200 m. Since 1966, Norpac net (Oceanographical Section, J. M. A., 1957) has been used instead of O-net and Automatic Opening-and-Closing Multiple net (KAWARADA and AKAMATSU, 1966) was used for sampling from various depths. Norpac net was hauled vertically upward from 150 m depth or from the bottom in shallower waters. Automatic Opening-and-Closing Multiple net which opens and closes automatically at intervals of 250 m successively was hauled from 1,000 m depth to the surface. These nets were made of bolting cloth GG54, $0.33 \times 0.33$ mm mesh aperture.

The numbers of cruises, sampling stations and hauls, stations where *C. philippinensis* were collected and the individual numbers of *C. philippinensis* are shown in Table 1.

Table 1. Plankton samples collected in the areas investigated

a. Deep layer (deeper than 200 m) samples

| Cruise | Nuber of sampling stations | Number of hauls | Number of stations where *C. philippinensis* were collected | Number of *C. philippinensis* per haul | Type of net* |
|---|---|---|---|---|---|
| 55–07 | 1 | 1 | 1 | 2 | C |
| 58–06 | 3 | 6 | 3 | 20 | C |
| 61–05 | 1 | 1 | 1 | 1 | C |
| 61–08 | 1 | 1 | 1 | 11 | C |
| 61–04 | 2 | 4 | 2 | 280 | C |
| 64–11 | 3 | 19 | 0 | 0 | C |
| 67–07 | 1 | 3 | 1 | 26 | A |
| Total | 12 | 35 | 9 | 340 | |
| b. Shallow layer (less than 200 m) samples | | | | | |
| 58–06 | 3 | 3 | 0 | 0 | O |
| 61–05 | 1 | 1 | 0 | 0 | O |
| 64–04 | 2 | 4 | 0 | 0 | O |
| 64–07 | 33 | 33 | 0 | 0 | O |
| 64–11 | 3 | 9 | 0 | 0 | O |
| 65–01 | 29 | 29 | 0 | 0 | O |
| 65–07 | 42 | 42 | 0 | 0 | O |
| 66–01 | 35 | 35 | 3 | 54 | N |
| 66–07 | 61 | 61 | 0 | 0 | N |
| 67–01 | 43 | 43 | 4 | 32 | N |
| 67–07 | 21 | 21 | 1 | 1 | N |
| Total | 273 | 281 | 8 | 87 | |
| Grand total | 285 | 316 | 17 | 427 | |

* C: C-net, A: Automatic Opening-and-Closing Multiple net, O: O-net, N: Norpac net

Table 2. Individual numbers of each growth stage of *Calanoides philippinensis*

| Station | | 4th stage copepodite | 5th stage copepodite | Adult |
|---|---|---|---|---|
| Deep layer samples | | | | |
| 55–07 | F–0 | | 2 | |
| 58–06 | E–8 | | 12 | |
| | I–d | | 7 | |
| | L–1 | | 1 | |
| 61–05 | I–4 | | | 1 |
| 61–08 | I–3 | | 11 | |
| 64–04 | S–4 | | 278 | |
| | CN–1 | | 2 | |
| 67–07 | X′–1 | | 26 | |
| Total | | | 339 | 1 |
| Shallow layer samples | | | | |
| 66–01 | S–5 | 5 | 25 | 1 |
| | S′–2 | | 6 | 1 |
| | G–6 | | 16 | |
| 67–01 | X–4 | | 1 | |
| | Y–3 | 4 | 23 | |
| | G–5 | | | 1 |
| | G–6 | | 3 | |
| 67–07 | C–5 | | 1 | |
| Total | | 9 | 75 | 3 |

With O-net and Norpac net, 280 plankton samples were collected at 273 stations during from 1958 to 1967 (called "shallow layer samples" in this paper). On examination 87 individuals of the species were identified at 8 stations. With C-net and Automatic Opening-and-Closing Multiple net, 35 samples were collected at 12 stations during from 1955 to 1967 (called "deep layer samples" here) and 340 individuals of *C. philippinensis* were found from the 11 samples at 9 stations.

The individual numbers of each growth stage of *C. philippinensis* are shown in Table 2. There were 3 individuals of the adult form, 75 individuals of the 5th stage of copepodite and 9 individuals of the 4th stage of copepodite in the shallow layer samples. Of the deep layer samples, all specimens were at the 5th copepodite stage exept an adult female.

### 3. Distribution

The vertical ranges of the shallow layer sampling in which *C. philippinensis* were collected are from the surface to 150 m depth and those of the deep layer sampling are from 224 m to 1,540 m depth.

The nine stations where *C. philippinensis* were collected from deep layers are scattered all over the Kuroshio regions of the East China Sea and the Pacific Ocean (Fig. 1). The maximum number of 240 individuals of *C. philippinensis* per a haul of net (19 inds./10 $m^3$) was counted in the sample which was collected by 518–1,159 m haul of C-net at the station 64–04, S4 (26–09N, 124–46E). At only three of the 12 stations no individual of the species was found in the deep layer. Therefore, it seems that *C. philippinensis* are very common in the deep water of the East China Sea.

All the shallow layer samples in which *C. philippinensis* were found were collected at the stations located along the edge of the continental shelf from latitude 25°N to 31°N. In other shallow layer samples, which were collected at more than 250 stations located in the inner parts of the continental shelf, the Kuroshio region and the Pacific Ocean, no specimen of *C. philippinensis* was found.

## 4. Discussion

KITOU and TANAKA (1969) reported that *C. philippinensis* were very common in the deep water of the South China Sea. As for the closely related species of the above forms, *C. carinatus,* many authors stated that immature forms of it were predominant in occurrence in the deep waters of the Atlantic, the Indian and the Antarctic Oceans (SCOTT, 1909. FARRAN, 1962, 1929. TANAKA, 1937, 1956, 1960, 1964. VERVOORT, 1951).

In the East China Sea *C. philippinensis* are very common in waters deeper than 200 m in the Kuroshio but entirely absent in the surface layers above the depth of 200 m or so in the Kuroshio region. Thus it can be said the species is an endemic species of the deep waters of the Kuroshio in the areas investigated.

Near the outer edge of the continental shelf, *C. philippinensis* are also present in considerable numbers in the waters between the sea surface and the continental shelf, the depth of which is about 120 m.

Figure 2 shows the vertical distributions of the water temperature and salinity in the section G shown in Figure 1, in the winter of 1967. The locations of the stations and the depths of the vertical hauls of a Norpac net in which *C. philippinensis* were found are shown with arrows. From the profiles of the water temperature and the salinity, it is supposed that similarity in nature between the bottom water of the continental shelf and the Kuroshio deep water in the layers of 300–500 m may reflect the continuation of both waters. FUKASE (1975) reported the existence of the characteristic water mass in the bottom layer at the outer edge of the continental shelf of the East China Sea, which was considered to have its origin in the deep layer of the Kuroshio.

Figure 3 shows the T–S diagrams at the stations where *C. philippinensis* were collected in the shallow layers compared to the mean curve of the Kuroshio (shown

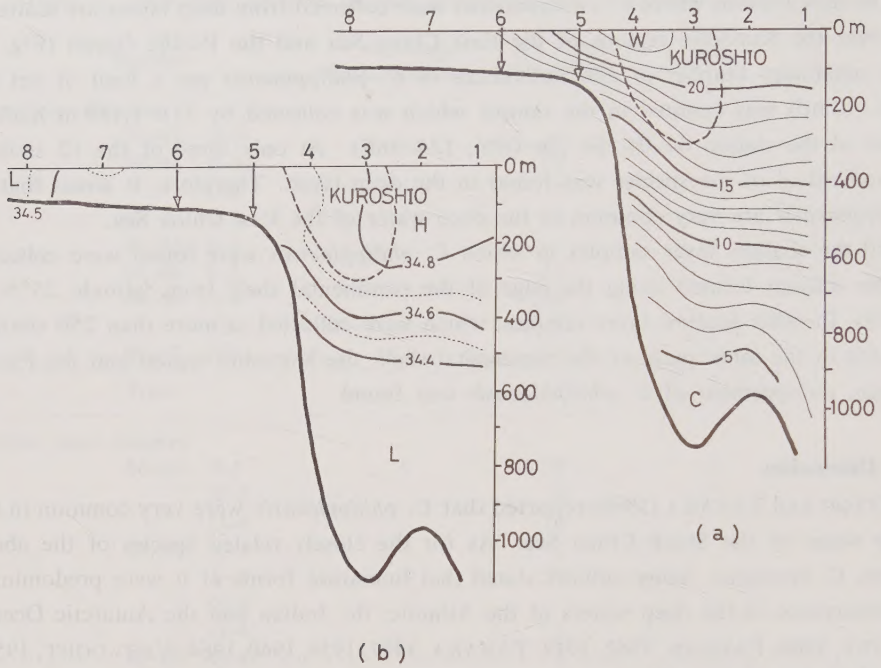


Fig. 2. Vertical distributions of water temperature (°C):(a) and salinity (‰):(b), in the section G in winter of 1967.
A mark —▷ denotes the stations and the vertical ranges of a Norpac net haul in which *C. philippinensis* were collected.

with a bold line). It is remarkable that the deeper waters of each station resemble, to some extent, the intermediate waters of the Kuroshio ranging between 200 m and 300 m depths. This fact becomes more apparent in summer (station 67–07·C5) than in winter (other stations) because in winter a considerable vertical mixing of water occurs by convection and the border between surface water and bottom water of the continental shelf becomes indistinct.

As the plankton net tow was made vertically from near the bottom to the surface in areas neighboring the outer edge of the continental shelf, it can not be known what depth *C. philippinensis* were caught. But from the facts mentioned above, it is considered that *C. philippinensis* are present in waters near the bottom of the outer edge of the continental shelf and probably are carried upward by the ascending water from the deeper layer of the Kuroshio to the continental shelf.

Considering the topography and the distribution of temperature-salinity relations in the East China Sea, AKAMATSU (1977) estimated that a part of the Kuroshiro climbs

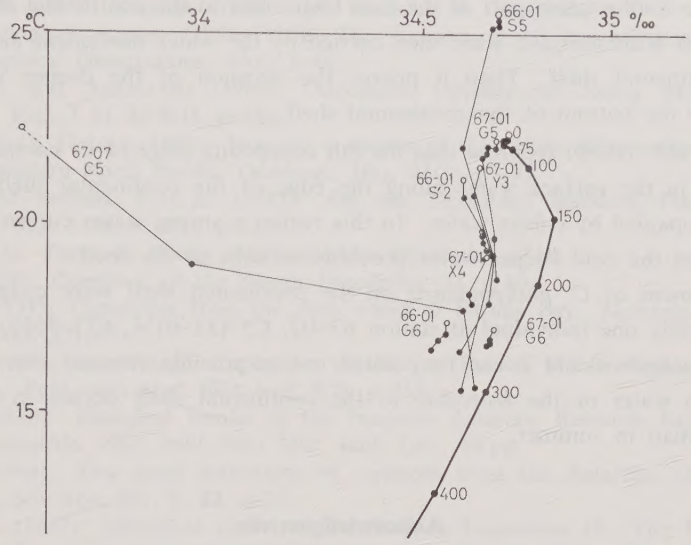


Fig. 3. T-S diagram at stations (66–01·S5, 66–01·S'2, 66–01·G6, 67–01·X4, 67–01·Y–3, 67–01·G5, 67–01·G6, 67–07·C5) where *C. philippinensis* were collected in the shallow layer samples. White circles show the *T–S* relations at the surface.
A bold line is the mean curve of the Kuroshio water in the East China Sea and the numbers show depths in meters.

up to the continental shelf at the southwestern part of the shelf. Then it flows over the continental shelf northeastward parallel to the Kuroshio and reaches the sea to the west of Kyushu. The distribution of *C. philippinensis* in the East China Sea coincides nicely with this estimation obtained by AKAMATSU.

KITOU and TANAKA reported that in the South China Sea the species appeared at the surface at the station just west of the Kuroshio where the water ascended from the deep. They also observed that the species show no diurnal vertical migration. KITOU and TANAKA further considered that in their young stage this species migrate to shallow water for feeding on phytoplankton and descend into deep water again in another stage of growth. But in the East China Sea it seems to be very difficult for the young copepods to migrate between the surface and the deep layers of the Kuroshio because the velocity of Kuroshio is very great along the continental slope in this area (Japan Meteorological Agency, 1951–1970).

The author concludes that *C. philippinensis* on the continental shelf ascended some-

where in the southwestern part of the East China Sea to the continental shelf from the deep layer of Kuroshio and were then carried by the water movement along the edge of the continental shelf. Then it proves the invasion of the deeper water of the Kuroshio to the bottom of the continental shelf.

BAINBRIDGE (1960) reported that the 5th copepodite stage of *C. carinatus* occurred abundantly in the surface water along the edge of the continental shelf off Guinea being accompanied by colder water. In this region a strong warm current flows along the shelf and the cold deeper water probably ascends to the shelf.

All specimens of *C. philippinensis* on the continental shelf were caught in winter except for only one individual at station 67–07, C5 (31–01N, 127–36E). The reason for this is unknown, but it can be pointed out as possibly relevant that the invasion of the deep water of the Kuroshio to the continental shelf occurs in winter more frequently than in summer.

## Acknowledgements

The author is greatly obliged to the late Dr. Masataka KITOU of the Maizuru Marine Observatory for his helpful suggestions and kind advice during the studies. He also expresses his hearty thanks to Dr. Yutaka KAWARADA for his critical reading of this paper and kind advice.

Hearty thanks are due to Dr. Shigeru FUKASE, the ex-director of the Oceanographical Section of the Nagasaki Marine Observatory, and to the staff of the section for their suggestions and encouragements. Thanks are also due to officers and crew of the R/V Chōfū Maru of the Nagasaki Marine Observatory, and of the Shumpū Maru of the Kōbe Marine Observatory for collecting the samples at sea.

## References

AKAMATSU, H. (1977): Origin of the Tsushima Current. Preprint Volume of the Autumnal Meeting of the Oceanographical Society of Japan, Kobe, 1977, 233–234. (in Japanese)

BAINBRIDGE, V. (1960): Occurrence of *Calanoides carinatus* (KRÖYER) in the Gulf of Guinea. Nature, **188**, 932–933.

FARRAN, G. P. (1926): Biscayan Plankton collected during a Cruise of H. M. S. "Research", 1900. Part XIV. The Copepoda. J. Linn. Soc. Lond., vol. **36**, 219–310.

FARRAN, G. P. (1929): Crustacea. Pt.10, Copepoda. British Antarctic (Terra Nova) Expedition, 1910. Nat. Hist. Rep., Zool., **8**(3), 203–306.

FARRAN, G. P. and W. VERVOORT (1951): Fiches D'identification du Zooplankton, **1**, 3–4.

FUKASE, S. (1975): Bottom Water on the Continental Shelf in the East China Sea. Kaiyo Kagaku, **7**(1), 19–26. (in Japanese)

GIESBRECHT, W. (1892): Pelagischen Copepoden des Golfes von Neapel, 120–123.

GIESBRECHT, W. and O. SCHMEIL (1898): Das Tierreich, **6**, Copepoda, p. 16.
Japan Meteorological Agency (1951–1970): The Results of Marine Meteorological and Oceanographical Observations. Nos. 5–41.
KAWARADA, Y. and AKAMATSU (1966): Automatic Opening-and-Closing Multiple Net. Oceanogr. Rep. J. M. A. **6**(1), p. 259.
KITOU, M. and O. TANAKA (1969): Note on a species of *Calanoides* (Copepoda, Calanoida) from the western North Pacific. Oceanogr. Mag. **21**(1), 67–81.
Oceanographical Section, J. M. A. (1957): On the NORPAC Standard Plankton Net. Oceanogr. Rep. J. M. A. **6**(1), p. 259.
ROSE, M. (1933): Faune de France, **26**, Copépodes Pélagiques, p. 10.
SCOTT, A. (1909): Copepoda of the Siboga Expedition (1), p. 10.
TANAKA, O. (1937): Copepodes from the deep water of Suruga Bay. Japanese Journal of Zoology **7**(1), 251–271.
TANAKA, O. (1956): The Pelagic Copepodes of the Izu Region Middle Japan, Systematic Account I. Publ. Seto Mar. Biol. Lab. **5**(2), p. 259.
TANAKA, O. (1960): Biological results of the Japanese Antarctic Research Expedition 10. Pelagic Copepoda. Spe. Publ. Seto Mar. Biol. Lab., 95 pp.
TANAKA, O. (1964): Two small collections of copepods from the Antarctic. Jap. Antarc. Res. Exp., Sci. Rep., Ser. E, **22**, 1–20.
VERVOORT, W. (1947): Biological results of the Snellius Expedition 15. The Bathypelagic Copepoda Calanoida of the Snellius Expedition. 1. Families Calanoidae, Eucalanidae, Palacalanidae and Pseudocalanidae. Temminckia, **8**, 1–181.
VERVOORT, W. (1951): Plankton copepods from the Atlantic sector of the Antarctic. Verhandlingen der Koninklijke Nederlandese Akademie van Wetenschappen Afdeeling Natuurkunde, Sec. **2**, Deel 47, 156 pp.
VERVOORT, W. (1963): Pelagic Copepoda Part I, Atlantide Report **7**, 81–82.

# 東シナ海における Copepoda の一種 *Calanoides philippinensis* KITOU et TANAKA の分布について

松 崎 正 夫
(気象庁海洋気象部)

従来，日本近海での ***Calanoides philippinensis*** の採集記録はほとんどないが，筆者は，1955～1967年に春風丸，長風丸が東シナ海およびその周辺海域で採取したプランクトン試料約300試料から，本種約400個体を得た。本種の特殊な分布状態と，水温，塩分による考察から，次のような結論を得た。

即ち，黒潮流域においては，その 150 m 以浅の表層からは全く見出されないにもかかわらず，200 m 以深の中～深層からはきわめて普通に記録されたことから，本種は東シナ海における黒潮の中～下層水のよい指標種となると考えられる。

一方，大陸棚の縁辺部すなわち黒潮流のすぐ内側において，150 m 以浅から約80個体が見出された。この海域の水温，塩分の鉛直分布や T-S ダイヤグラムによる解析から，黒潮の中層水の大陸棚底層への侵入がうかがえるが，本種の出現もまたそれをよく裏付けていると思われる。

The Oceanographical Magazine
Vol. 29, Nos, 1-2, pp. 11 to 22, March 1978

# On diurnal changes in the amount of chlorophyll *a* and phaeophytin in the inlet waters
# I. Changes of chlorophyll *a* and phaeophytin in relation to those of chemical elements and phytoplankton in Maizuru Bay in April, 1974

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(Received August 31, 1976; revised January 9, 1978; accepted January 11, 1978)

***Abstract***: Diurnal changes in the amounts of chlorophyll *a* and phaeophytin in Maizuru Bay were checked by examining seventy two sea water samples collected at the surface, 2 m and 7 m depths successively in 27 hours from April 23 to 24, 1974 at the site (9 m deep) of an ocean data buoy anchored in the inner part of the bay. At the same time, plankton samples were collected and the diurnal changes of the standing crops, together with those of the concentrations of some chemical elements, were compared with the changes in the amount of the above-mentioned pigments.

Chlorophyll *a* and phaeophytin were most copious at 7 m depth. The difference in the amount of these pigments between the surface and the bottom layers seem to suggest that the surface and bottom water masses were quite separate from each other. The relationship between chlorophyll *a* and chemical elements was evidently different as between the surface and the bottom water masses.

## 1. Introduction

As to the diurnal changes in the amounts of chlorophyll *a* and phaeophytin, SAIJO (1963) reported that in the natural phytoplankton population, the amount of chlorophyll and photosynthetic activity varied with the time of day, and that in the Indian Ocean, photosynthesis at the surface goes in the morning three times as actively as in the afternoon. KAWARADA and SANO (1968) studied the diurnal variations in the standing crops of diatoms and dinoflagellates and in the amount of chlorophyll *a* in the sea water sampled every six hours in Sagami Bay and stated that the amount of chlorophyll *a* per single phytoplankton cell decreased logarithmically with the increase of the cell number in the standing phytoplankton population.

Thus, it is clear that the analysis of the horizontal distribution of phytoplankton, especially in the polluted inlet waters of rich nutrients, cannot be achieved satisfactorily unless the pattern of the diurnal change in the amount of phytoplankton is fully understood.

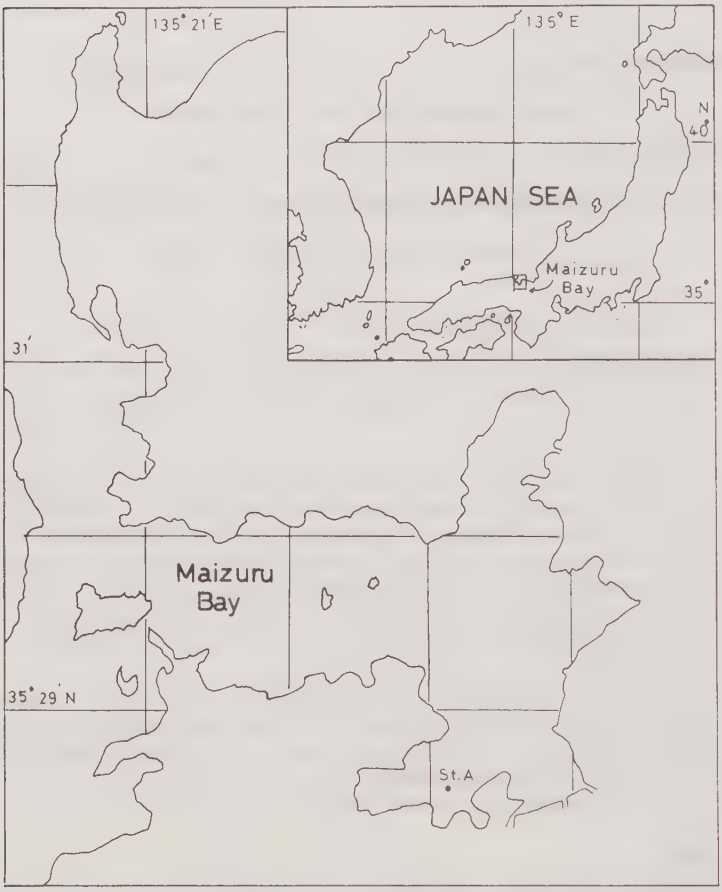


Fig. 1. Map of Maizuru Bay showing the position of Station A, where the observation and sampling were made from Apr. 23 to 24, 1974.

During the oceanographical survey of Maizuru Bay on the Japan Sea coast of middle Honshu (Fig. 1), special efforts were made to investigate the diurnal changes in the amount of chlorophyll *a* and phaeophytin in the bay water.

Based on the analysis it was noted that the amounts of chlorophyll *a* and phytoplankton standing crops were higher at 7 m depth than at the surface and 2 m depth. This seemed to suggest that the nature of the water mass was somewhat different between the surface and the bottom in Maizuru Bay. Some essential difference between the surface and the bottom water in the bay has been predicted by the appearance of a cold water copepod, *Pseudocalanus minutus* KRÖYER, in the bottom water in March;

this species had never been found in the surface water in the bay (UEDA: 1974, unpublished; FURUHASHI: 1975).

To confirm the above mentioned point, the amounts of chlorophyll *a* were compared with the concentrations of dissolved oxygen, nitrite nitrogen and phosphate phosphorus.

## 2. Material and method

Meteorological and oceanographical observations were made on an ocean data buoy fixed at Station A, 9 m deep, in the inner part of Maizuru Bay from 9:00 h of 23 to 12:00 h of the next day in April, 1974. At the same time, twenty four water samples were taken from the surface, 2 m and 7 m depths, respectively, by a Kitahara's water sampler. The amounts of chlorophyll *a* and phaeophytin in 100 ml of sea water were determined by the fluorometric method (YENTSCH and MENZEL: 1965; SAIJO and NISHIZAWA: 1969) and major species of phytoplankton contained in 300 ml of sea water were identified and counted under the microscope, after they were concentrated by decantation and then with a centrifuge.

## 3. Diurnal changes of the amounts of chlorophyll *a* and phaeophytin at the respective water depths

Diurnal changes of the amount of chlorophyll *a* ($\mu$g/l) at three depths are shown in Figure 2. At the surface the amount varied from 4.58 to 9.48, averaging 7.16$\pm$1.34; and at 2 m depth the amount ranged from 3.86 to 8.28, averaging 5.79$\pm$1.07; and at 7 m depth the amount ranged from 13.0 to 22.6, averaging 17.59$\pm$2.55. The amounts of chlorophyll *a* fluctuated more widely at 7 m depth than at the surface or 2 m depth—more than two times as much as at the surface and three times as much as at 2 m depth.

Diurnal changes of the amount of phaeophytin ($\mu$g/l) at three depths are shown in Figure 3. The amount at the surface varied from 1.78 to 8.68, averaging 3.26$\pm$1.24; at 2 m depth from 2.50 to 4.71, averaging 3.42$\pm$0.65; and at 7 m depth the amount, with a peak on the morning of 23rd and 24th, ranged from 5.40 to 13.98, averaging 8.48$\pm$2.10. This was evidently higher than at the other depths as in the case of chlorophyll *a*.

## 4. Diurnal changes of phytoplankton at respective water depths

Diurnal changes of the percentage of dominant diatom species at the surface and 7 m depth are shown in Figures 4 and 5 respectively. The most dominant species was *Eucampia zoodiacus* at both depths, occupying 29 to 47% at the surface and 55 to 76% at 7 m depth. The proportion of this species to the total diatoms at 7 m depth

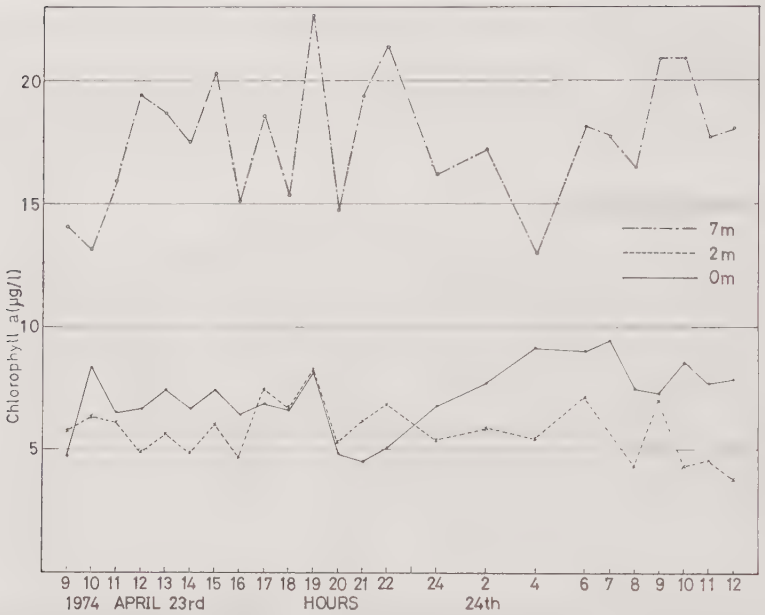


Fig. 2. Diurnal changes of the amount of chlorophyll *a* (μg/l) at the surface (solid line), 2 m (dotted line) and 7 m (broken line) depths.

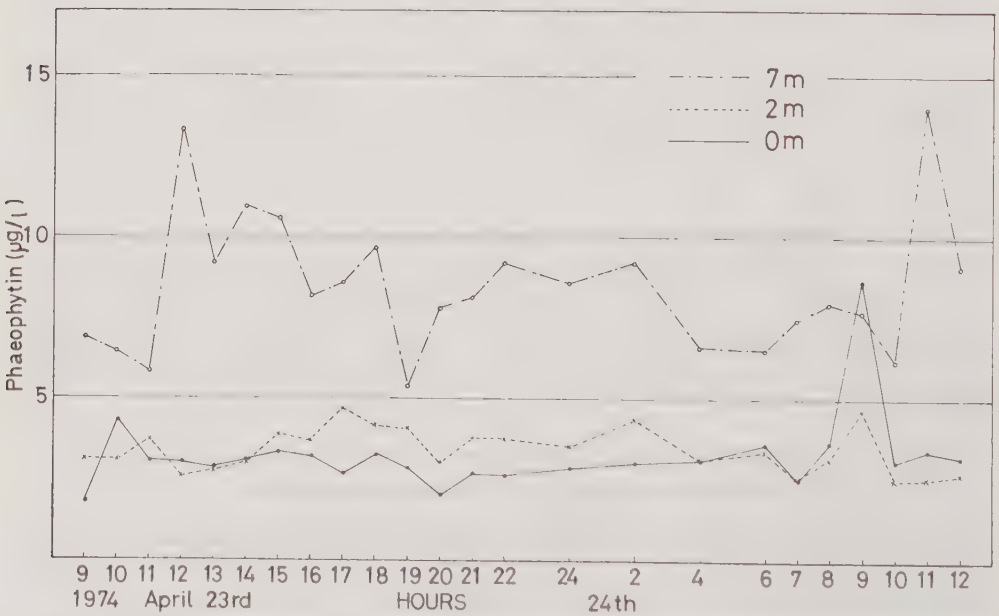


Fig. 3. Diurnal changes of the amount of phaeophytin (μg/l) in the surface (solid line), 2 m (dotted line) and 7 m (broken line) depths.

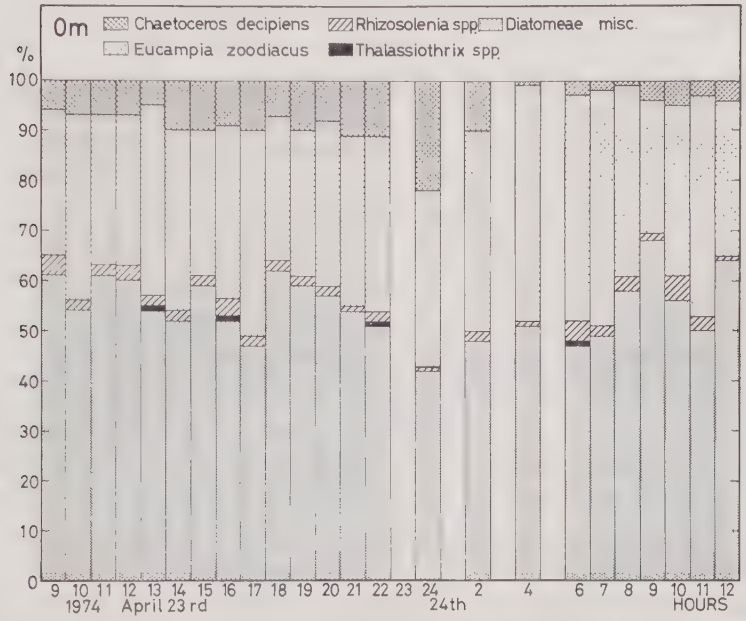


Fig.4. Diurnal changes of the diatom compositions at the surface.

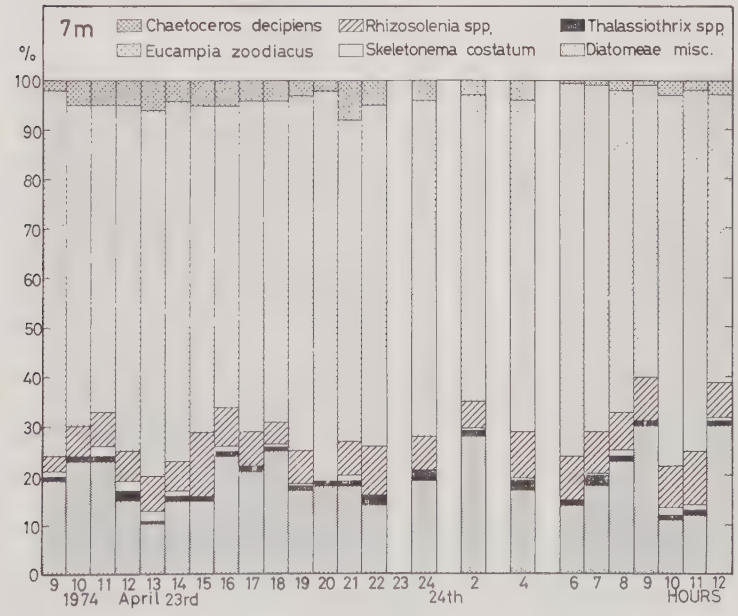


Fig. 5. Diurnal changes of the diatom compositions at 7 m depth.

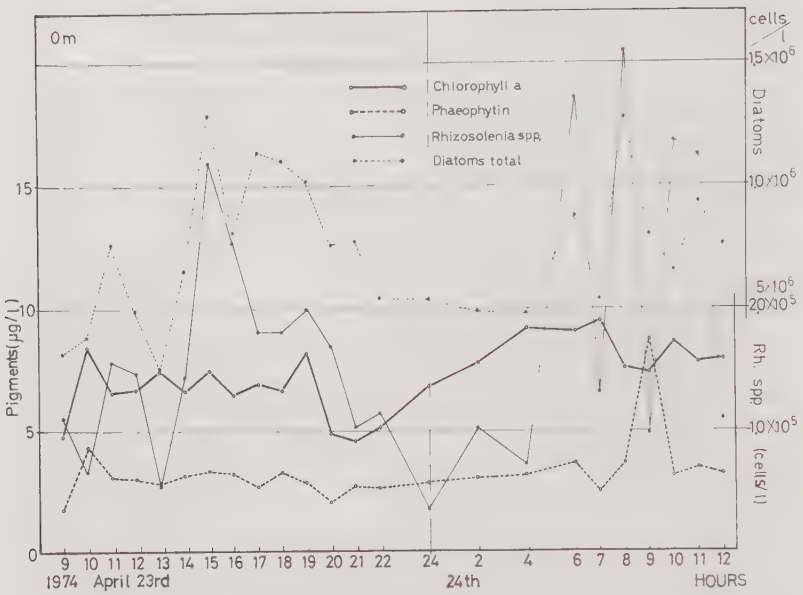


Fig. 6. Diurnal changes of the amount of chlorophyll *a* and phaeophytin, and cell number of *Rhizosolenia* spp. and the total diatoms at the surface.

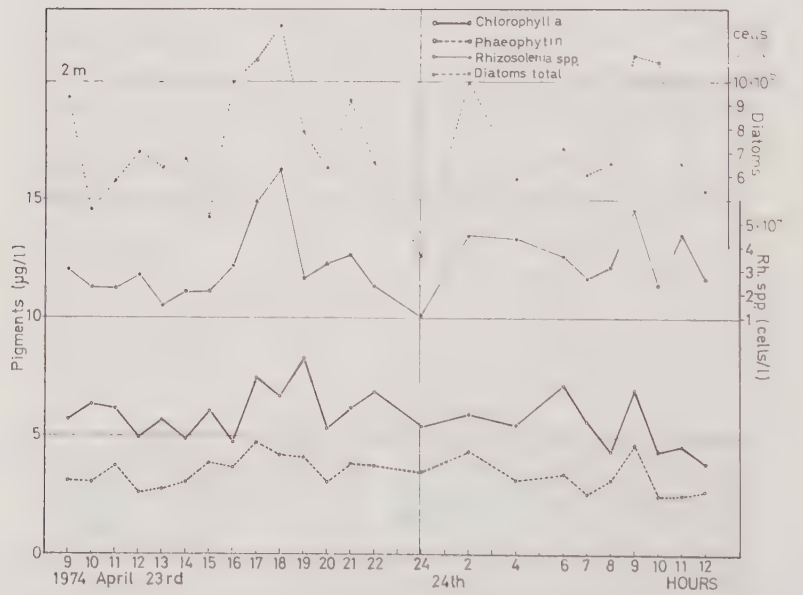


Fig. 7. Diurnal changes of the amount of chlorophyll *a* and phaeophytin, and cell number of *Rhizosolenia* spp. and total diatoms at 2 m depth.

was more stable on 23rd, fluctuating in the range of 61–76%, than on 24th, fluctuating in the range of 55–76%. The proportions of large sized diatoms such as *Rhizosolenia* spp. and *Thalassiothrix* sp. were different between the surface and 7 m depth as seen in the figures.

It was noteworthy that *Skeletonema costatum* was mostly limited to 7 m depth, though it was also found in the samples collected at 2 m depth at 9:00, 17:00 and 24:00 on 23rd. This species was completely missing in the surface samples at this time, although it was the most abundant species in surface water in Wakasa Bay and the outer part of Maizuru Bay from January to April, 1962, accounting for more than 70% of total diatoms (MAIZURU MARINE OBSERVATORY: 1964).

In order to see the relationships between chlorophyll *a*, phaeophytin and phytoplankton, diurnal changes of these at the surface, 2 m and 7 m depths are plotted on the same sheet in Figures 6, 7 and 8 respectively.

At the surface the amount of chlorophyll *a* was almost constant in the daytime on Apr. 23, though it suddenly decreased at 20:00 h when polluted water formed the surface at this station (KITOU and EGUCHI: 1975; FURUHASHI: 1976); after midnight the amount gradually increased toward the dawn. The percentages of chlorophyll *a* to the total pigments (chlorophyll *a* plus phaeophytin) ranged from 62.8 to 79.1 and averaged

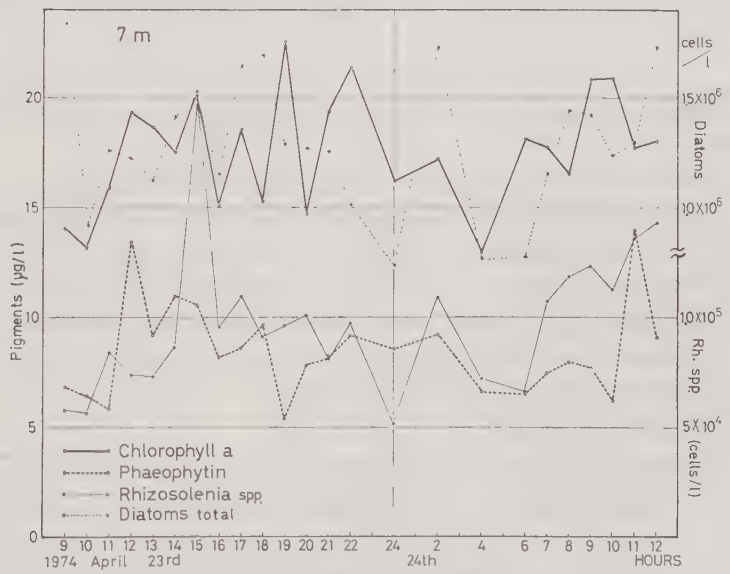


Fig. 8. Diurnal changes of the amount of chlorophyll *a* and phaeophytin, and cell number of *Rhizosolenia* spp. and total diatoms at 7 m depth.

70.0±3.5 at the surface except at 09:00 h on Apr. 24. Cell numbers of the total diatoms and large sized diatoms *Rhizosolenia* spp. seemed to increase in the daytime, while they decreased by night at the surface.

At 2 m depth fluctuations in the amounts of chlorophyll *a* and phaeophytin were very small, and the percentages of chlorophyll *a* to the total pigments ranged from 56.1 to 67.7 and averaged 62.8±3.3. The cell number of the total diatoms showed two peaks respectively at 18:00 on Apr. 23 and 9:00 on Apr. 24 and was lowest at midnight, though this fluctuation did not accord with that in the amounts of chlorophyll *a* and phaeophytin.

The diurnal changes were much more evident at 7 m depth not only in the amount of the pigments but also in the percentage of chlorophyll *a* to the total pigments, which ranged from 55.9 to 80.7 and averaged 67.6±5.5. Total diatoms were also most abundant at 7 m depth, where the mean cell number was about 1.8 times as large as at the surface and 2 m depth.

It was noted that both the phytoplankton standing crops and the amount of pigments were largest not only in the daytime but also in the night at 7 m depth.

In addition, the percentage of chlorophyll *a* to the total pigments was very high at 7 m depth. Taking the difference found in the diatom composition between the surface and bottom layers into consideration, all the features mentioned above seem to show that the water mass was somewhat different in nature between the surface and bottom layers.

### 5. Relation between the amounts of chlorophyll *a* and the concentrations of chemical elements

The relation between the amounts of chlorophyll *a* and concentrations of three chemical elements was checked. The relation between the amount of chlorophyll *a* and the concentration of dissolved oxygen at three depths is plotted in Figure 9, which shows clearly that the relation at 7 m depth is unlike those seen at the surface and 2 m depth. The water was oversaturated with dissolved oxygen throughout the observations at the surface and 2 m depth, while it was unsaturated at 7 m depth in spite of the existence of a large amount of chlorophyll *a*.

The relation between the amount of chlorophyll *a* and the concentration of nitrite nitrogen is plotted in Figure 10. This figure shows that the increase of the concentration of nitrite nitrogen caused by polluted water at the surface (KITOU and EGUCHI: 1975) is related with the slight decrease in the amount of chlorophyll *a*, while at 2 m and 7 m depths no relationship was seen between these two cases. The relations between the amount of chlorophyll *a* and the concentration of phosphate phosphorus at three depths are plotted in Figure 11. This figure shows that the increase in the

concentration of phosphate phosphorus is related with the decrease in the amount of chlorophyll *a* at the surface, but the relationship is reversed at 2 m and 7 m depths.

Fig. 9

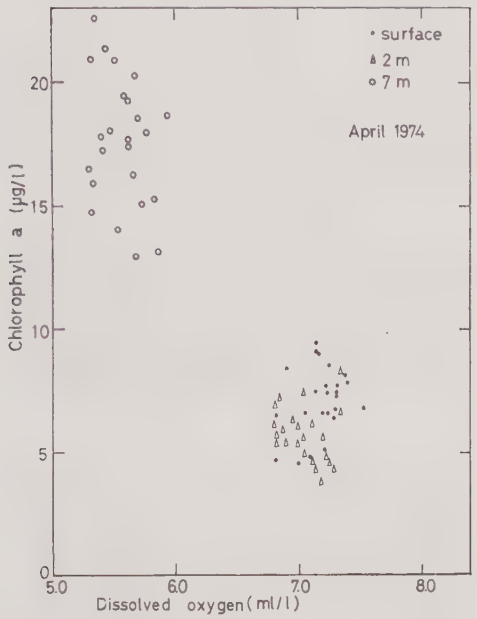


Fig. 10

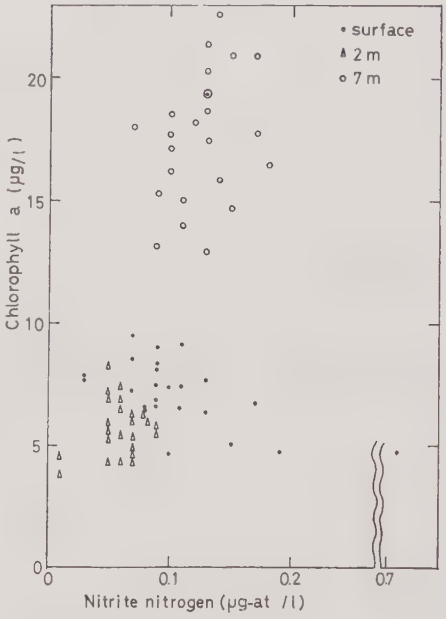


Fig. 11

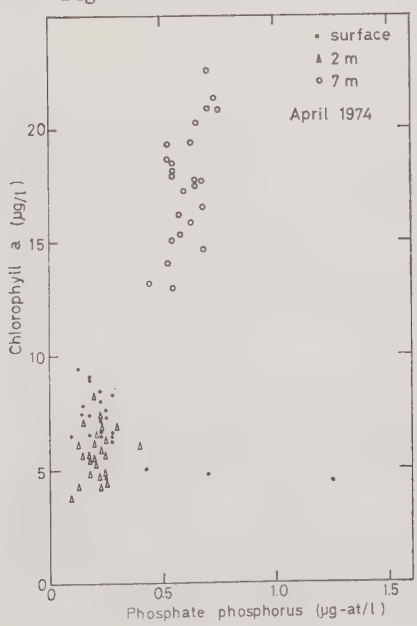


Fig. 9. Relationship between the amount of chlorophyll *a* (μg/l) and the concentration of dissolved oxygen (ml/l) at the surface, 2 m and 7 m depths.

Fig. 10. Relationship between the amount of chlorophyll *a* (μg/l) and the concentration of nitrite nitrogen (μg-at/l) at the surface, 2 m and 7 m depths.

Fig. 11. Relationship between the amount of chlorophyll *a* (μg/l) and the concentration of phosphate phosphorus (μg-at/l) at the surface, 2 m and 7 m depths.

## 6. Conclusion

Though the present materials were collected from only one station in Maizuru Bay, the difference between the surface and the bottom waters obtained for the spring season is noteworthy.

The amounts of chlorophyll *a* and phaeophytin were twice as large at 7 m depth as at the surface and 2 m depth. The total cell number of diatoms was also larger at 7 m depth than at the surface and 2 m depth. The relationships between the amount of chlorophyll *a* and the concentrations of dissolved oxygen, nitrite nitrogen and phosphate phosphorus suggested that the watermass at 7 m depth was clearly separated from those at the surface and 2 m depth.

HASHIMOTO (1973) calculated the vertical stability of sea water using the monthly mean water temperature and salinity in the western part of Wakasa Bay from 1952 to 1962, and stated that in the innermost part of the Tango-Kai (near the outer part of Maizuru Bay) the water is very stable throughout the year, while it is unstable in the outer part of the Tango-Kai in winter.

Without vertical mixing of water in winter, the large concentration of dissolved oxygen in the bottom water in Maizuru Bay throughout the year would never be explained. The appearance of cold water copepod in the bottom water in March and the diatom blooming also there in April synchronizing with that in Wakasa Bay, all seemingly pointed toward the replacement of the bottom water in Maizuru Bay by the cold water underlying the Tsushima Warm Current from late winter to early spring.

## Acknowledgements

The authors wish to express their hearty thanks to Prof. Takasi TOKIOKA for his kindness in reading the manuscript and to Mr. Hideo AKAMATSU of the Nagasaki Marine Observatory for his generosity in giving the authors the chance to carry out the present study, and also to the members of the Oceanographical Section of the Maizuru Marine Observatory for their kindness is helping them in collecting samples.

## References

FURUHASHI, K. (1975): Studies on the Boreal Water Species of Copepods found in the Japan Sea. Part 1. The path of *Pseudocalanus minutus* KRÖYER (Copepoda) found in the Heart of the Maizuru Bay from the Boreal Waters in the Japan Sea. Umi to Sora, **51**(1), 35–39. (in Japanese)

————. (1976): Diel vertical migration suspected in some copepods and chaetognaths in the inlet waters, with a special reference to behavioural differences between male and female, noted in the former. Publ. Seto Mar. Biol. Lab., **22**(6), 355–370.

Hashimoto, Y. (1973): The General Properties of the Oceanographic Conditions in the Western Parts of Wakasa Bay (the Tango-Kai). Umi to Sora, **49**(3), 69–84. (in Japanese)
Kawarada, Y. and A. Sano (1968): Diel Variations of Phytoplankton, Chlorophyll *a* and Photosynthesis. Bull. Plankton Soc. Japan, **15**(1), 7–10. (in Japanese)
Kitou, M. and I. Eguchi (1975): On the Diurnal Variation of Chemical Elements in the Maizuru Bay. Umi to Sora, **51**(1), 41–48. (in Japanese)
Maizuru Marine Observatory (1964): The Results of Marine Meteorological and Oceanographical Observations. Japan Meteorological Agency, No. 3, January to June, 1962, 216–220.
————. (1974): The Results of the Oceanographic Observations in the Western Part of Wakasa Bay and Maizuru Bay in May, 1974. Oceanographic Prompt Reports, Supplement for No. 268. (in Japanese)
Saijo, Y. (1963): Problem in the Study of Primary Production in the Sea. Inform. Bull. Plankton. Japan, No. 10, 9–17. (in Japanese)
Saijo, Y. and S. Nishizawa (1969): Excitation spectra in the fluorometric determination of chlorophyll-*a* and phaeophytin-*a*. Mar. Biol., **2**, 135–136.
Yentsch, C. D. and D. W. Menzel (1963): A method for the determination of phytoplankton chlorophyll and phaeophytin by fluorescence. Deep-Sea Res., **10**, 221–231.

# 内湾におけるクロロフィル a とフェオフィチンの日変化について

## 1. 1974年4月に舞鶴湾で観測された植物色素と化学成分および植物プランクトンの比較

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1974年4月23日09時から24日12時まで，深夜を除いて毎時間計24回の観測が舞鶴湾奥の水深 9 m の A 点に定置された2号ブイの上で実施された。気象要素と化学成分については既に報告されているので，ここでは植物色素含有量と植物プランクトンの日変化を中心に述べた。

化学成分の場合と同様に，汚染された内湾水の影響と潮汐による変化が大きく，本来の目的である日変化は解明できなかった。ただ，けい藻類総細胞数が表層で日中に多く夜間に少ない傾向を示した。

植物色素量の定量および植物プランクトンの計数のため，表面，2 m および 7 m の3層で，それぞれ 100 ml と 300 ml の同時採水を行った。鉛直分布をみると，植物色素量，植物プランクトン現存量ともに 7 m 層の値は，表面と 2 m 層の 2～3 倍を示した。このように表層より底層に多い鉛直分布は他の季節にはみられない。溶在酸素は表面と 2 m で過飽和であるが，7 m では不飽和であっ

た。一方，全植物色素量に対するクロロフィル *a* の百分比は，表面と 2 m で平均して 70.0 と 62.8%であるのに 7 m では 67.6% となっていた。これらの関係を考察するために，クロロフィル *a* の量と，酸素，亜硝酸態チッソおよびリン酸態リンとを比較した。その結果，表面と 2m との値はよく一致するのに，7 m 層ではこれらの値と著しく離れた値を示した。

以上の結果と，3 月に舞鶴湾底層に冷水性のプランクトンが出現した事実と合せ考えると，春季に舞鶴湾の底層水と沖合冷水の分枝が交換する可能性を暗示するものと考えられる。

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# The ratio of nitrate to phosphate in seawater of the Pacific

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***Abstract***: The distribution of the nitrate to phosphate ratio in seawater of the Pacific is studied in detail. The N/P ratio in the surface water is less than 5 in most places except in the Subarctic, the eastern Equatorial and to the south of the Antarctic region. In the deep water, the ratio is less than 13 in the Subarctic region and is nearly 14 in the South Pacific. Waters which are characterized by more than 16 and less than 10 of the ratios are found respectively in the Western Antarctic region and the sea area off Mexico. In the Pacific, in general, it is found that most of the ratios range from 13 to 14.

## 1. Introduction

Since the constancy of the N/P ratio (15:1 by atoms) both in seawater and in plankton was shown by REDFIELD (1934), many investigations have been done on the N/P ratio mainly in coastal or near-the-surface waters. KETCHUM et al. (1958) and STEFÁNSSON and RICHARDS (1963) pointed out that this ratio varies geographically and seasonally in coastal or near the surface waters. COOPER (1938) showed that it varies with geographical locations in the North Atlantic where the waters from the Mediterranean Sea flow in.

Little, however, is known on the vertical and geographical distribution of this ratio in the seawater of the Pacific. In this paper, the distribution of the N/P ratio in seawater is described over the entire Pacific, not only in the surface but also in the deep layers. The ratio in this paper is expressed as atom ratio obtained from the observed values of both reactive nitrate and phosphate in seawater.

## 2. Data sources

Since the development of the method of nitrate determination using copper-cadmium reduction column (WOOD et al.: 1976, and STRICKLAND and PARSONS: 1968), a number of reliable data have been accumulated on the content of nitrate in the seawater of the Pacific (see SAGI: 1977).

During the three big expeditions in the Pacific on board the R. V. Hakuho Maru which belongs to the Ocean Research Institute, University of Tokyo, and some of the

Table 1. List of cruises relevant to this study

| Cruise | Dates | Meridional section surveyed | Reference |
|---|---|---|---|
| Ry 69–5 | 1–21 May 1969 | 155°E, 30°N–48°N | a |
| Ry 72–6 | 2 June–27 July 1972 | 155°E, 30°N–11°S | b |
| KH 68–4 | 22 Nov. 1968–1 Feb. 1969 | 155°E, 63°S–42°S | c |
| | | 170°W, 30°N–70°S | |
| KH 70–2 | 14 April–18 June 1970 | 170°W, 50°N–30°N | d |
| | | 140°W, 17°N–50°N | |
| KH 71–5 | 26 Nov. 1971–11 Feb. 1972 | 146°W–100°W, 17°N–65°S | e |
| | | about 100°W, 65°S–15°N | |

a: The results of marine meteorological and oceanographical observations, Japan Meteorological Agency, No. 45 (1971).
b: The results of marine meteorological and oceanographical observations, Japan Meteorological Agency, No. 52 (1974).
c: Oceanographic data of KH 68-4 (Southern Cross Cruise) of the Hakuho Maru, Ocean Research Institute, University of Tokyo, (1970).
d: Preliminary report of the Hakuho Maru Cruise KH 70-2 (Great Bear Expedition), Ocean Research Institute, University of Tokyo, (1971).
e: Oceanographic data of KH 71-5 (Phoenix Expedition) of the Hakuho Maru, Ocean Research Institute, University of Tokyo, (1973).

cruises in the western North Pacific on board the R. V. Ryofu Maru which belongs to the Japan Meteorological Agency, the same quality of the analytical data for nitrate and phosphate has been obtained.

In table 1, the names and dates of the cruises which were related to this study are summarized. The locations of the sampling stations are shown in Fig. 1.

Phosphate was determined by the stannous chloride reduction method (ROBINSON and THOMPSON: 1948) during the cruises of KH 68–4 aboard the R. V. Hakuho Maru and by the ascorbic acid reduction method (MURPHY and RILEY: 1958) during other cruises. Errors on the N/P ratio which are estimated from analytical errors in nitrate and phosphate determination in seawater is less than 5% of the reported value.

### 3. Geographical distribution of N/P ratio

The frequency distribution of the N/P ratio in waters in the entire Pacific is shown in Fig. 2-a. The distributions in surface (0–100 m), intermediate (100–1000 m) and deep (>1000 m) waters are also shown in Figs. 2-b, c, and d respectively. As seen in Fig. 2-a, the value of N/P ratio in the waters of the Pacific as a whole ranges from

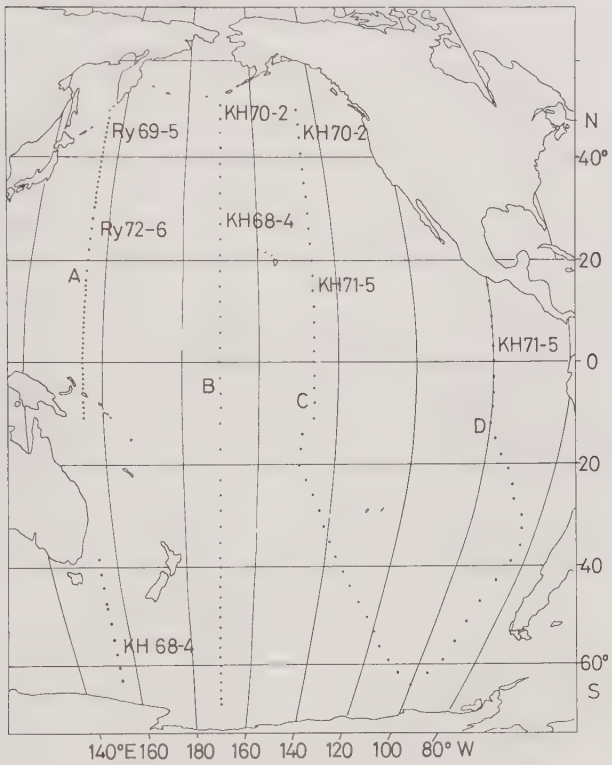
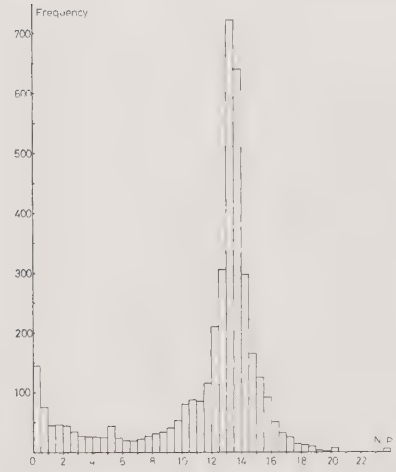


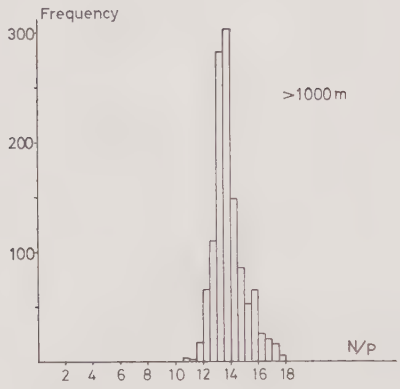

Fig. 1. Location of four long sections (A, B, C and D) relevant to this study.

0 to 20 or more with a maximum frequency between 13 and 14. The distribution pattern in the surface layer is different from the other two layers. In the intermediate and deep waters, the frequency distribution of N/P ratio shows nearly normal with a maximum value of 13 to 14 as shown in Figs. 2-c and d. However, in the surface waters, the N/P ratio ranges from 0 to about 20 and shows no particular trend, as seen in Fig. 2-b.

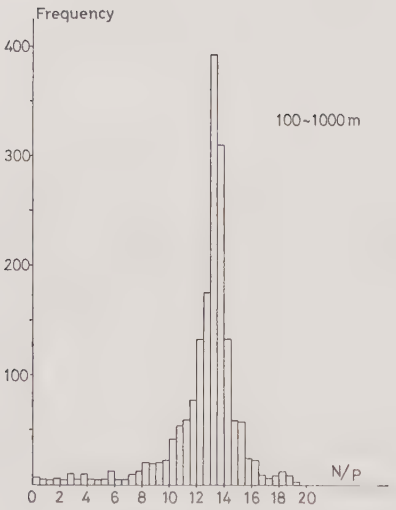
Fig. 3 shows the distribution of the N/P ratio in the surface waters of the Pacific. It is seen in Fig. 3 that in most areas of the ocean surface, the N/P ratio is less than 5, but in three areas of the ocean, i.e., south of the Subantarctic, the Subarctic, and the eastern Equatorial region, the ratio exceeds 10. Since, in most areas of the ocean surface phosphate still remains even after the photosynthetic activity reaches its maximum, the lowering of the N/P ratio may be ascribed to the depletion of nitrate. However, in the latter three regions, it is presumed that deep water with a high N/P ratio is brought up to the surface by vertical mixing or upwelling.



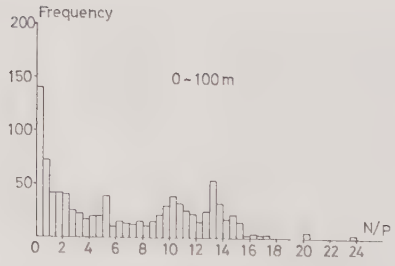

(2—a)




(2—b)




(2—c)




(2—d)

Fig. 2. Frequency distributions of the N/P ratio in the sea water of the entire Pacific (2-a), surface layer (2-b), intermediate layer (2-c) and deep layer (2-d).

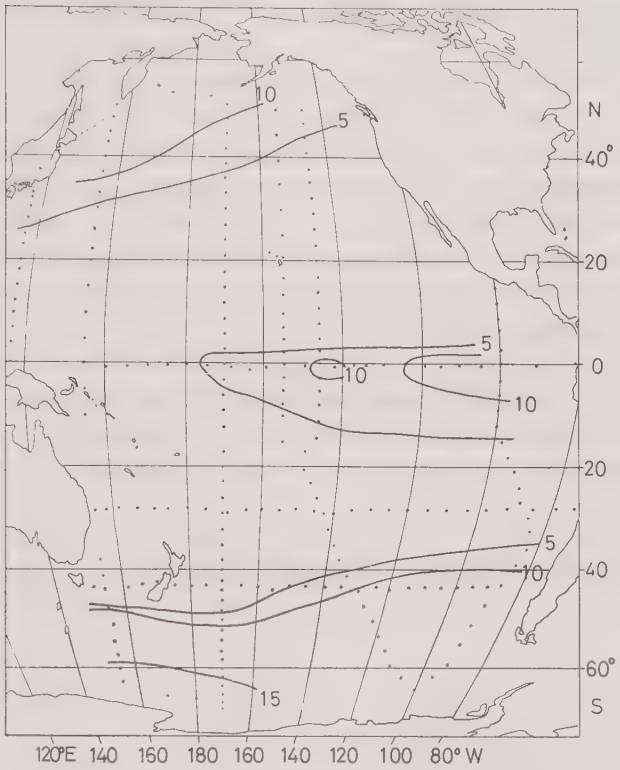



Fig. 3. Geographical distribution of the N/P ratio in the surface water of the Pacific.

**4. Meridional distribution of N/P ratio, nitrate, and phosphate concentration**

Meridional distributions of the N/P ratio, nitrate, and phosphate contents in seawater are shown respectively in Figs. 4, 5, and 6.

In A section along 155°E from the Kurile Islands to the Coral Sea and to the Antarctic Ocean, the Kuroshio front and the Oyashio front are situated at about 34°N and 40°N. The two streams are mixing between these latitudes, and nitrate and phosphate concentrations in $\mu$g·at/l range from 5 to 40 and 0.5 to 3.0 respectively. The N/P ratio in surface water ranges between 10 and 12 in the mixing area and exceeds 15 north of the Oyashio front. In the region south of the Equator between 400 and 800 m in depth, nitrate and phosphate concentrations in $\mu$g·at/l range from 25 to 35 or more and 1.8 to 2.5 respectively, as the result of which the N/P ratio slightly higher than 14 is found in this region. In the deep water, near the Antarctic Ocean nitrate and phosphate concentrations in $\mu$g·at/l range from 30 to 35 and

slightly more than 2.0 respectively. Waters with the N/P ratio greater than 16 are seen in this region.

In B section along 170°W from the Aleutian Islands to the Antarctic Ocean, nitrate and phosphate concentrations in $\mu$g·at/l ranging from 35 to 40 and 2.5 or more to 3.3 respectively are observed in regions to the north of the middle latitudes and South Pacific at depths greater than 1000 m. From these results, ratios between 12 and 13 in the former and more than 14 in the latter are found. In regions south of the Antarctic Convergence, the average content of nitrate and phosphate in seawater shows 35 and 2.0 $\mu$g·at/l, respectively. Water which is characterized by 16–18 of the ratio is found in this region as shown in Fig. 4 (B).

In C section from off Alaska to the Antarctic region, a maximum higher than 14 of the ratio appears at depths between 200 and 500 m in the region to the north of 10°S. In these areas, concentrations of nitrate (10–35 $\mu$g·at/l) and phosphate (1.0–3.0 $\mu$g·at/l) steeply increase with depth. Nitrate and phosphate concentrations in

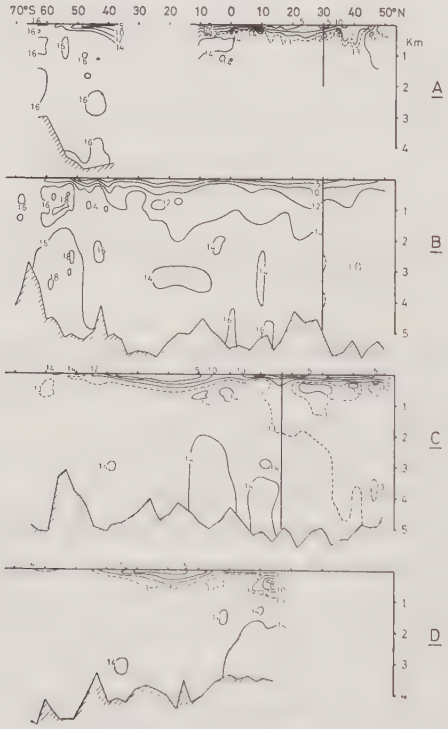



Fig. 4. Distribution of the N/P ratio along A, B, C and D line in Fig. 1.

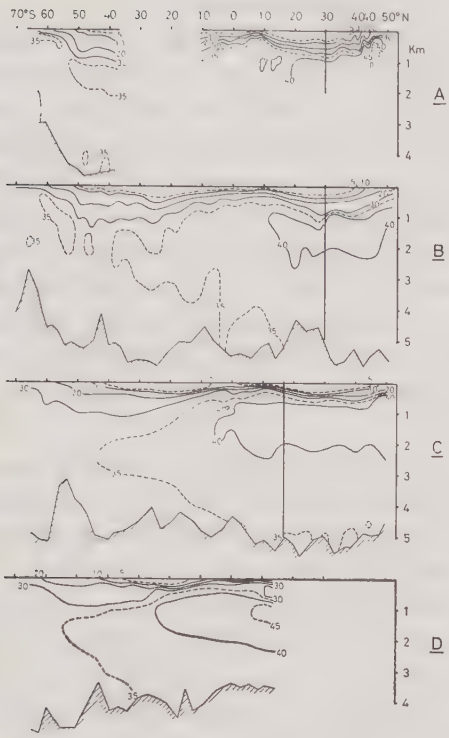



Fig. 5. Distribution of nitrate along A, B, C and D line in Fig. 1.

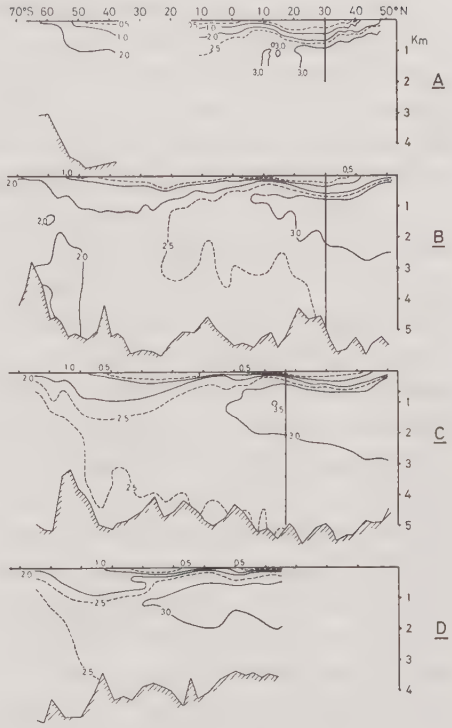



Fig. 6. Distribution of phosphate along A, B, C and D line in Fig. 1.

$\mu$g·at/l range from 35 to 43 and 2.7 to 3.3 respectively in deep layers in the Subarctic and the Subtropical regions. The waters show a ratio less than 13 in these regions, while the deep waters in the South Pacific contain 30–40 $\mu$g·at/l of nitrate and 2.0–3.0 $\mu$g·at/l of phosphate, and show a ratio greater than 13 or 14 in some regions near the bottom.

In D section from the sea area off Mexico to the Antarctic Ocean, lower N/P ratios below 10 are found in intermediate waters off Mexico to the north 10°N. Such a low ratio results only from depletion in nitrate concentration of 30 $\mu$g·at/l because the phosphate amount larger than 2.5 $\mu$g·at/l is nearly the same as that in surrounding waters. Except in intermediate waters in this region and the surface waters of D section, the N/P ratio seems to be rather uniform between 13 and 14, though nitrate and phosphate contents in seawater range rather widely from 20 to 45 and 1.5 to 3.3 $\mu$g·at/l respectively as seen in Figs. 4 (D), 5 (D) and 6 (D).

**5. Relations of N and P to the N/P ratio in the distinctive region**

As mentioned in the previous paragraph, the N/P ratio in waters in the Pacific changes not only vertically but also regionally corresponding to the variation of nitrate, phosphate or both. Changes in the N/P ratio are mainly due to the mixing of various kinds of waters differing with respect to nitrate and phosphate content. Provided that the relation of N/P ratio to the concentration of nitrate and phosphate is available for an analysis of the character of water mass, these relations are plotted as shown in Fig. 7-a and b respectively. Except in the surface water containing nitrate less than 20 $\mu$g•at/l, the waters in the Subarctic region are divided into the western and the eastern region. A higher ratio in the western Antarctic region and a lower ratio in the sea off Mexico are prominent. It is also clear that a higher N/P ratio in the western Subarctic region is due to higher nitrate and lower phosphate concentrations than those in the eastern Subarctic region.

In the case of the sea off Mexico, things are somewhat different. To demonstrate such a low N/P ratio in this region, the vertical distribution of the N/P ratio, nitrate and phosphate concentrations (Fig. 8-c) are compared with those in the temperate zone (Fig. 8-b) and the Subarctic and the Antarctic regions (Fig. 8-a). As shown in Figs. 8-b and 8-c, nitrate and phosphate concentrations in surface water are depleted in regions within the temperate zone and the sea area off Mexico where a thermocline develops remarkably in shallow layers. It is, however, shown in Fig. 8-a that nitrate and phosphate in surface water are enriched in the Subarctic and the Antarctic regions. In Fig. 8-c, it is to be noted that the nitrate profile shows a lower value between depths 300 and 500 m, but the phosphate profile shows a rather normal relation between concentration and depth, as the result of which a remarkably low N/P ratio is found. Such a low nitrate concentration in this area may be explained by denitrification process in the eastern Tropical North Pacific found by CLINE and RICHARDS (1972).

The remarkably high N/P ratio in the western Antarctic region can be explained by the relatively low concentration of phosphate compared with the other parts of the ocean. On this basis it is presumed that waters with rather low phosphate but slightly higher nitrate contents sink to the deep in this region through Antarctic convergence.

The relations of nitrate and phosphate concentrations to the N/P ratio may be useful to clarify the character of the water mass in the Pacific.

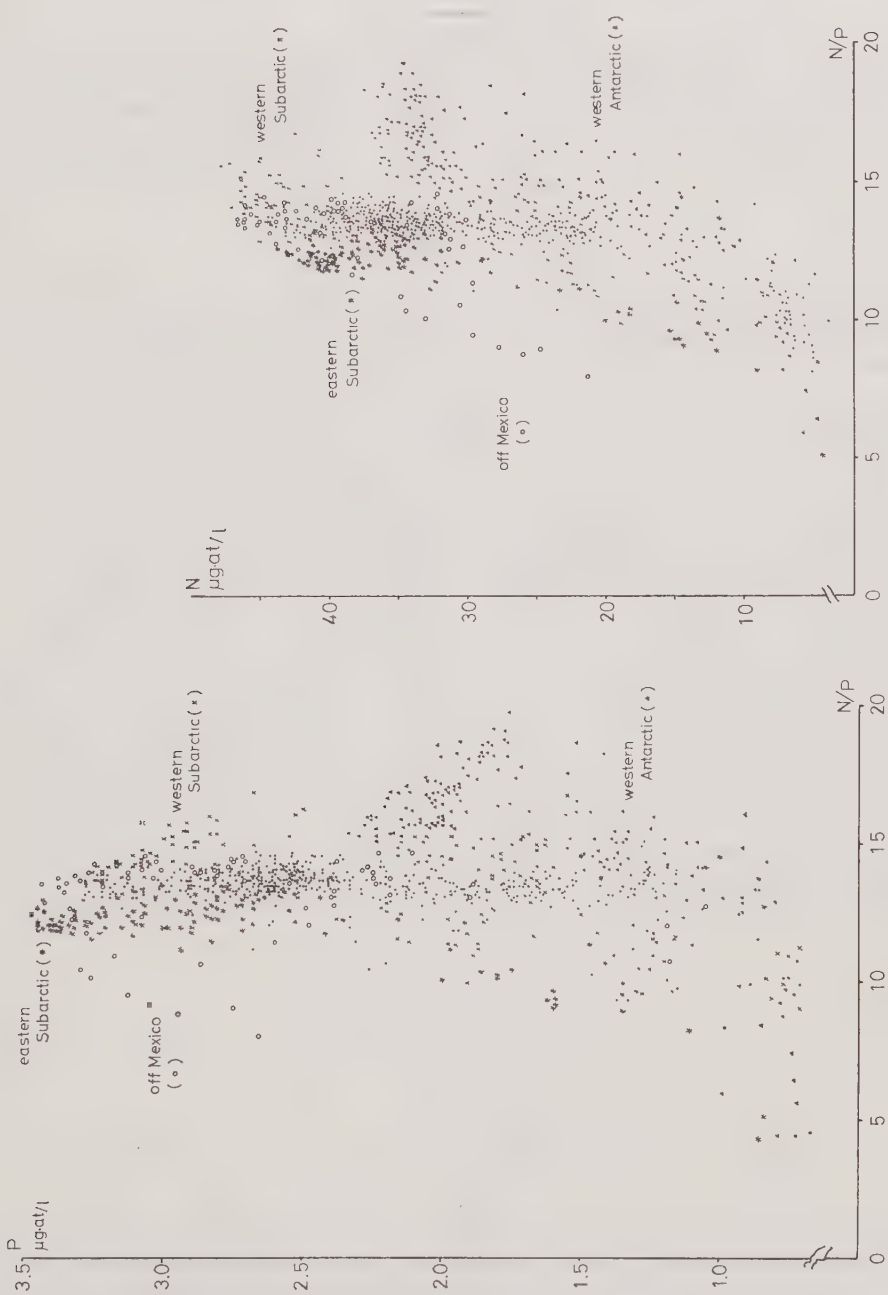
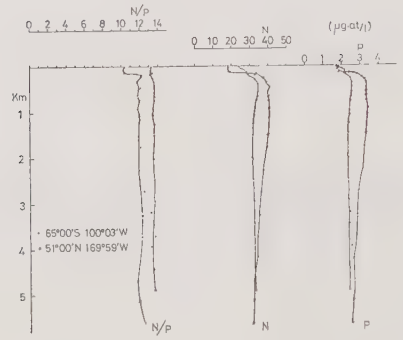
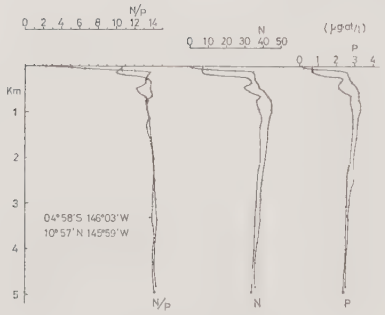


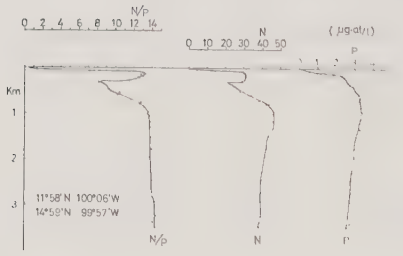

Fig. 7. Relations of nitrate (7-a) and phosphate (7-b) to the N/P ratio.




(8—a)




(8—b)




(8—c)

Fig. 8. Vertical distributions of the N/P ratio, nitrate and phosphate in $\mu g \cdot at/l$ in regions of the Antarctic and the Subarctic (8-a), temperate zone (8-b) and off Mexico (8-c).

**Acknowledgements**

The author wishes to express his hearty thanks to Prof. Y. MIYAKE, President of the Geochemistry Research Association, for his kind advice and suggestions. His thanks are also extended to the earnest discussion by Drs. Y. SUGIURA, K. SARUHASHI and Y. SUGIMURA of the Meteorological Research Institute.

**References**

CLINE, J. D. and F. A. RICHARDS (1972): Oxygen deficient conditions and nitrate reduction in the eastern Tropical North Pacific Ocean. Limnol. Oceanogr., **17**, 885–900.

COOPER, L. H. N. (1938): On the ratio of nitrogen to phosphorus in the sea. J. Mar. Biol. Ass. U.K., **22**, 177–182.

KETCHUM, B. H., R. F. VACCARO, and N. CORWIN (1958): The annual cycle of phosphorus and nitrogen in New England coastal waters. J. Mar. Res., **17**, 282–301.

MURPHY, J. and J. P. RILEY (1958): A single-solution method for the determination of soluble phosphate in sea water. J. Mar. Biol. Ass. U.K., **37**, 9–14.

REDFIELD, A. C. (1934): On the proportions of organic derivatives in sea water and their relation to the composition of plankton. James Johnstone Memorial Volume, Liverpool, 177–192. Cited from A. C. REDFIELD, B. H. KETCHUM, and F. A. RICHARDS (1963): The influence organisms on the composition of sea water, in M. N. HILL ed.: The Sea, **2**, 26–77.

ROBINSON, R. J. and T. G. THOMPSON (1948): The determination of phosphates in sea water. J. Mar. Res., **7**, 33–41.

SAGI, T. (1977): On the distribution of nitrate nitrogen in the Pacific Ocean. Pap. Met. and Geophys., **28**, 29–39.

STEFÁNSSON, U. and F. A. RICHARDS (1963): Processes contributing to the nutrient distributions off the Columbia river and strait of Juan de Fuca. Limnol. Oceanogr., **8**, 394–410.

STRICKLAND, J. D. H. and T. R. PARSONS (1968): Determination of reactive nitrate, in "A practical handbook of seawater analysis", Fish. Res. Bd. Can., Bull., 71–76.

WOOD, E. D., F. A. J. ARMSTRONG, and F. A. RICHARDS (1967): Determination of nitrate in sea water by cadmium-copper reduction to nitrite. J. Mar. Biol. Ass. U.K., **47**, 23–31.

## 太平洋海水中の N/P 比

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太平洋で海水中の N/P 比の分布を調べた。全資料では，13～14に山をもつ正規分布となるが，100 m 以浅のものは一定の傾向を示さない。表面水では，熱帯および亜熱帯の広い海域で5以下の低い N/P 比を示すが，亜南極海より南の海域，亜寒帯海域，東部赤道海域では 10 以上を示す。

1000 m 以深の深層では，一般に北太平洋より南太平洋の方が幾分高く，亜寒帯海域で13以下，

南太平洋は14に近い。

亜寒帯海域の中深層では N/P 比の幾分高い西側と低い東側とに分れそうである。メキシコ沖には10以下の N/P 比で特徴づけられる水塊がある。

155°E 線と 170°W線の南極海には 16 以上の N/P 比を示す中深層水がある。これは低いリン酸塩濃度の水が存在するためで，南極収れん線付近で沈降する比較的リン酸塩濃度の低い水の影響と思われる。

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